DEVELOPMENT OF ORTHORECTIFIED CIR IMAGERY

Fundamentals of Using CIR Aerial Photography to Map Wetlands

The broad spectrum of electromagnetic energy emitted by the sun ranges from short wavelength gamma rays to long wavelength radio waves. This spectrum has been categorized into energy types, such as ultraviolet (UV) radiation, infrared radiation (IR or heat), and visible light (Figure 5). Within the visible spectrum most plants reflect green light in the visible range, which is detected by the human eye. Plants that are actively growing (undergoing photosynthesis) also reflect a significant amount of infrared energy, which is not visible to the human eye. In fact, plants reflect enough infrared energy that CIR photographs can be used to detect differences between different plant communities that are not visible to the human eye. Similar to standard color film, CIR film is sensitive to the green and red wavelengths of light that reflect from objects on the earth. Additionally, the CIR film is able to detect the infrared light reflected by objects.

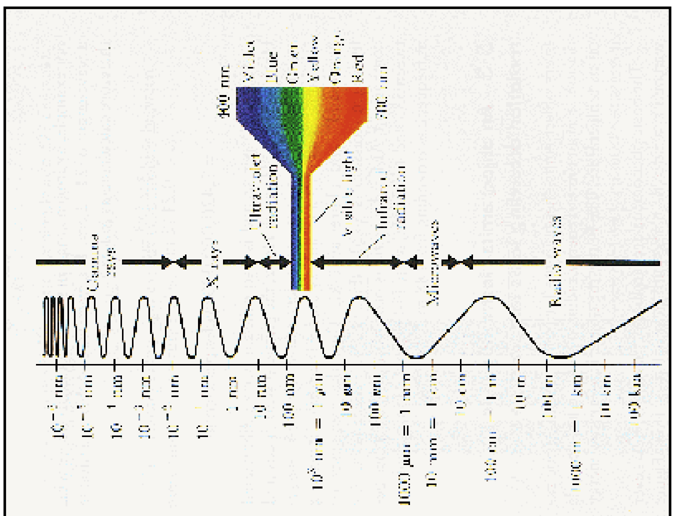

Figure 5. Energy types and wavelengths in the electromagnetic spectrum. Source: Blair, B., Hopkins Ultraviolet Telescope (http://praxis.pha.jhu.edu/science/emspec.html)

When sunlight strikes the leaf of an actively growing plant a large amount of infrared light is reflected. The sensitivity of the CIR film to the infrared light allows for recording the areas of high infrared reflectance associated with the actively growing vegetation. As a result, healthy, photosynthesizing plant communities appear bright red on CIR film instead of the visible green color displayed on standard color film. More accurately, the film used is referred to as *False Color Infrared* film. This is due to the fact that while the film is sensitive to light energy in the visible spectrum, when exposed the colors visible on the photographs are not true colors. For example objects that appear blue to the human eye, such as water, show up as black on the CIR photograph. Objects that appear red to the human eye tend to show up on the CIR photograph as green.

Areas covered by vegetation that is dead or dying tend to show up as shades of white and grey. This is due to the way that visible light and infrared radiation is reflected from the plants. Figure 6 shows the difference in reflectance from an actively growing leaf and a dying leaf. The first illustration in this figure shows the green and infrared light being reflected from a mature leaf structure as the blue and red light is absorbed. Since the infrared light is invisible to the human eye, the leaves display a prominent green color. In the second illustration, this same leaf has completed its growing cycle and the spongy mesophyll layer has been depleted of moisture and intracellular air space. The spectral result of this change is that blue and red light are no longer absorbed by the leaf and are reflected along with green and infrared to give the leaf a brighter and more washed out color.

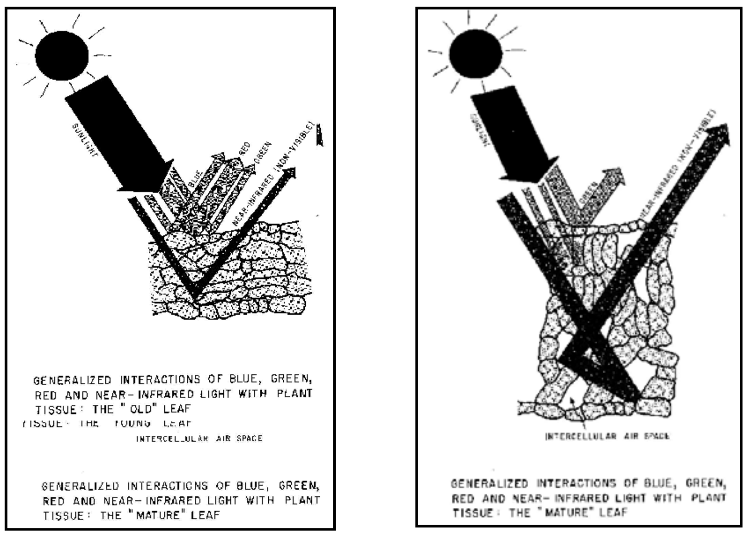

Figure 6. Comparison of visible and infrared light reflection from actively growing verses dying leaf structures (Samson, S.A. 2000)

CIR imagery was used in this wetland identification project to capitalize on the spectral differences occurring in local plant communities during the month of September. Similar to most of the inter-mountain west, warm temperatures, low humidity, and low precipitation dominates the August through September weather in south-central Montana. The lack of moisture during this period promotes plant senescence (die off) in upland plant communities by September. However, the prevalence of water in wetland areas enables many of these plant species to continue growing until colder temperatures limit plant function.

Color Infrared Aerial Photography of the Gallatin Valley

The color infrared (CIR) aerial photography of the Gallatin Valley was taken on September 9, 2001. The flight was timed so that it was between the end of the growing season and before the first killing frost for most upland plants. By September, most of the plants that were still actively photosynthesizing were either being irrigated, growing in sub-irrigated areas (shallow ground water), or growing in wetland and riparian areas.

Montana Aerial Photography out of Missoula, Montana conducted the flight. The photos were taken from about 12,000 feet above ground level. The combination of flight altitude, land-surface elevation, and photo frame size (9-inch by 9-inch), resulted in a photo scale of about 1:24,000. To cover the project area 14 flight lines were flown and 252 photographs were taken. The spacing of the flight lines and photo frames along the flight lines were set so that there was 60% overlap between photos along a flight line and 30% overlap from one flight line to the next. This allowed for viewing the photographs in three dimensions using a stereoscope. The flight line map and a complete set of color prints for the flight were obtained and are available for viewing at the Gallatin Local Water Quality District office in Bozeman, Montana.

Transforming CIR Aerial Photographs Into Digital Photographs

Once the aerial photographs were obtained they were transformed into digital photographs that could ultimately be processed into digital orthophoto quadrangle (DOQ) maps (explained below). Steps were taken to preserve as much detail as possible from the original photographs so that the aerial photography could be used to identify wetland and riparian areas on the computer screen using ArcView™ GIS software. The film from the aerial photography flight was developed as a color positive and shipped to Michael Baker Jr., Inc., in Beaver, Pennsylvania to be scanned. Scanning the color positive film, rather than the contact prints, helped to preserve the details of the images.

Michael Baker Jr., Inc. used a high-resolution photogrametric scanner to scan each photo frame. This also aided in preservation of the original image quality. Each photo frame was scanned at a setting of 907 dots per inch (dpi), which is equal to an image pixel size of 28 microns. The images were "dodged" when scanned to help reduce the effects of shadows and bright spots on the photographs. Each scan file was then saved as a TIFF format digital image with the file name matching the flight line number and photo number. For example file 01-12 was the file name assigned to photo number 12 on flight line number 1. Due to the high dpi setting used to scan the frames, the resulting file size for each TIFF image was 209 megabites. The TIFF files were saved on both compact discs (CD) and digital video discs (DVD). To store the data it took 85 CDs and 12 DVDs.

Orthorectification of Digital CIR Photographs and Creation of CIR DOQs

The scanned TIFF images were processed and compiled into DOQ maps that covered the same areas as published U.S. Geological Survey 7.5-minute quadrangle maps. The file names used for the CIR DOQs matched the 7.5-minute quadrangle names. The goal was to create digital images that could be used as base maps in ArcView™ GIS software. The process of converting the scanned TIFF images is referred to as orthorectification, and required specialized software and skills. David Moody, with GISPix in Bozeman, Montana, was hired to complete the orthorectification, and provided the following details on how the aerial photographs were processed.

The software used to process the digital CIR photographs was PCI Geomatics™. The type of digital photogrammetry used to orthorectify the imagery is referred to as aero triangulation. The software uses the principles of triangulation to correct the photography in the x and y direction and incorporates the use of a digital elevation model (DEM) for the vertical (z) direction. The first step in the aero triangulation was to create an interior orientation by registering the fiducial marks (corner marks) of the aerial photographs. At the start of the project a camera calibration report (a very accurate description of the different types of distortion associated with the camera used to take the pictures) was entered into the system. The computer then used the measurements taken from the fiducial marks and computed them against the camera calibration report to create the “interior orientation” of the block model. For each TIFF image an interior orientation was calibrated.

The majority of time spent orthorectifying the photographs was spent obtaining ground control and tie points used to calculate the exterior orientation of the model. The ground control came entirely from points on 1995 black and white U.S. Geological Survey DOQs. The horizontal accuracy of these DOQs followed the National Map Accuracy Specifications that 90% of the points on image are within 40 feet of their true position. A total of 1082 ground control points were used for the project area, providing an even distribution of control throughout the project area. The root mean square value (RMS) for the project area was**: X-1.27 meters and for the Y-1.28 meters**. The highest RMS value for a ground control point accepted in the model was 5 meters, (in a few locations where there was a large discrepancy in accuracy between overlapping DOQs).

The other labor-intensive step was to obtain tie points between the images. A total of 1075 tie points were selected for the project area. The tie points help the computer recognize where the aerial photographs overlap and provide another point of reference by the software. The RMS score for the tie points was as follows: **X-.10 meters, Y-.07 meters**. After all the ground control points and tie points were established the software was able to generate orthophotos from each of the raw TIFF images.

The orthogeneration process created a single image (orthophoto) at a time, representing a subsetted area of each individual scanned image. The image created was a subset of the entire scanned photo so as to use only the most accurate portion of each aerial photograph (which is a towards the center) and so as not to include the periphery features, such as fiducial marks in the scanned image. It was possible to subset considerably as there was an average of 60% endlap and 30% sidelap for each photograph.

For vertical control 30-meter DEM data obtained from the USGS National Elevation Database was used in the orthorectification software. The DEM data were used by the processing software to adjust the horizontal position geometrically for topographic displacement. As a quality control measure for the project, each individual image created was swiped with the 1995 USGS black and white DOQ coverage for the same area to examine for inconsistencies in the images. The most common source of error came from points that were sharing overlapping positions on DOQs.

After the individual orthophotos were created it was necessary to mosaic the images to make the final DOQs, which are mosaics of individual orthophotos. Mosaics were created that would cover the same area as the corresponding USGS 7.5-minute quadrangles. This process was completed using the PCI Geomatics™ software, which performed the difficult task of choosing the best possible cut-lines in the overlapping images to most effectively produce a seamless appearance on the final mosaic. The computer selected the portions in overlapping photos that had the highest brightness value, which helped to eliminate shadows and dark areas. The mosaics created were larger than the desired quadrangle and it was necessary to subset (trim) the mosaics to match the 7.5-minute quadrangle boundaries. The images were cut to the NAD 83 tics on the 7.5-minute quadrangles to create the final DOQ maps.

The final products were 19 complete or partial CIR DOQs for the project area with a pixel resolution of 0.66 meters (2.2 feet). To allow for viewing the entire project area on the computer screen at one time, all of the images were also mosaiced into single images at resolutions of 5 and 10 meters. These files were much smaller and easier to handle. All of the CIR DOQ images were saved on DVDs. These DVDs have been provided to the Montana Natural Resources Information Center (NRIS), the USGS National Map project (http://nationalmap.gov), interested Gallatin County and City of Bozeman Departments, and a number of local consulting firms. They can also be obtained from the Gallatin Local Water Quality District. Table 4 lists the files available for the imagery.

Table 4
Color Infrared Digital Orthophoto Files

DVD #	USGS Quadrangle (file name)	File Size (MB)	Full Quad	NWI Maps
1	Anceney	940	Yes	Yes
1	Cherry Creek	35.6	No	No
1	Logan	228	No	No
1	Madison Plateau	528	No	Yes
1	Manhattan	945	Yes	Yes
1	Manhattan Southwest	517	No	Yes
1	Nixon Gulch	442	No	Yes
2	Ruby Mountain	938	Yes	No
2	Gallatin Gateway	949	Yes	Yes
2	Bozeman Hot Springs	949	Yes	Yes
2	Belgrade	938	Yes	Yes
2	Horseshoe Creek	411	No	Yes
3	Flathead Pass	457	No	No
3	Miser Creek	928	Yes	Yes
3	Bozeman	935	Yes	Yes
3	Wheeler Mountain	869	Yes	No
4	Saddle Peak	807	Yes	No
4	Mount Ellis	1,290	Yes	No
4	Kelly Creek	813	No	No
5	5-Meter Mosaic (not USGS)	281	N/A	N/A
5	10-Meter Mosaic (not USGS)	69.2	N/A	N/A